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PHOTO PLOT BIAS

Forest inventories

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ABSTRACT

The photo intensity, or number of aerial photos per unit of land surface, was examined for six Agricultural Stabilization and Conservation Service photo projects in western Oregon and Washington. On each of the six projects, lands that were primarily nonforest were found to have more photos per unit of area than did the forest lands. Overall, photo intensity averaged 4.1 percent greater on nonforest than forest areas. This suggests a serious source of bias in any forest inventory using photo plots with an equal number of plots per photo. There was no evidence that this difference in photo intensity was associated with elevation differences. The problem can be avoided by transferring plot locations from maps to photos.

Keywords: Aerial photography, forest surveys, photography.

INTRODUCTION

Extensive forest inventories often use information from plots located on aerial photographs. Where the features of interest are easily recognized on the photos, the survey may be done entirely by photo interpretation with no ground checking. Such a procedure has been recommended for surveys to estimate the acreage in logging roads (*11*). Where the features of interest are subject to photo interpretation error, the sampling design usually calls for field checking a portion of the photo plots in order to adjust for these errors, a procedure known as double sampling. This is the method most commonly used by U.S. Government agencies for extensive forest inventories. It is also used to some extent in Canadian forest inventories and in other parts of the world.

Foresters have long been aware that information obtained from aerial photos runs the risk of being biased because the photos seldom picture land areas in their true proportions. This risk of bias can be avoided if the sample plot locations are first chosen on a map, then transferred to the photos by radial line or stereoplotter instruments, or it can be reduced by using a controlled mosaic. However, these processes are time consuming and expensive, and there is a tendency to gravitate to the much easier method of locating the same number of plots on each contact print by means of a transparent grid, or by printing the plots on the photos.

As yet, there has been no complete evaluation made of all the sources of bias inherent in such a procedure. Two studies (*10*, *16*) of bias caused by change of photo scale in rough country have concluded that the problem is apparently not serious. The literature contains several recommendations for overcoming the possible bias from scale change, including keeping the plots at or near the photo centers (*16*); using radial line methods to locate plot clusters on stereopairs (*1*, *7*); and adjusting the initial photo plot count for elevation differences (*8*, *12*, *13*).

As a result, the inventory forester will find little in the existing literature to discourage him from locating his plots on the photos with a systematic grid which produces the same number of plots on each photo. The consensus in current references (*2*, *3*, *4*, *6*, *9*, *14*, *15*) is that this procedure is unbiased as long as variations in ground elevation are small in relation to flying height. If the terrain is rough, opinion is divided. Some authorities suggest that the method is acceptable even when the topographic range is a substantial portion of the flying height. Others warn about the risk of bias from scale change but suggest that this risk can be eliminated by one of the recommended adjustment procedures.

However, there is another source of bias in photo plot sampling that has not been given the recognition it deserves. This bias is caused by the fact that the photos in a given project are seldom uniformly distributed over the earth's surface. If a photo index map or mosaic is examined, it will be seen that there are usually variations in the spacing between photos along and between flight lines. Often extra partial flight lines are spliced in to cover areas of insufficient sidelap. As a result, the photo intensity, or number of photos per unit of land area, varies from place to place within the project area.

If plot locations are chosen at random on the photos, or systematically by taking the same number of plots on each photo, then the plots will tend to be concentrated in those areas where photo intensity is greatest, and conditions present in those areas will be sampled at a higher rate than the remaining areas. This situation can occur in photo projects over flat terrain as well as rough country, and the procedures for eliminating bias due to photo scale change do not necessarily correct for bias caused by variations in photo intensity. It is important to recognize that any bias caused by nonuniform photo distribution can be in addition to the bias that may result from elevation change. And such bias is not removed by the field checks made in a double-sampling procedure. Thus, the threat of bias from nonuniform photo intensity is present in any inventory that locates equal numbers of plots on each aerial photo or at random on the photos.

Many inventory foresters have recognized this source of bias and have devised schemes for minimizing it. However, the fact that it has not been adequately recognized in the existing literature, and that many inventories still ignore it, suggests that there is a need to call attention to it.

OBJECTIVES

In order to get some idea of the magnitude and consistency of this source of bias in some typical aerial photo projects, a cooperative study was undertaken by the Pacific Northwest Forest and Range Experiment Station, U.S. Forest Service, and the School of Forestry, Oregon State University. Its purpose was to measure the uniformity of photo spacing or photo intensity and to determine if variations in intensity were related to the major land class breakdown of forest-nonforest or to ground elevation. These results would provide a basis for estimating the amount of bias that might be expected in a forest inventory based on equal numbers of plots located on each photo.

The breakdown of forest and nonforest was chosen because it is a critical one in any forest inventory. If all photo plots are given equal weight, but forest and nonforest plots have unequal probabilities because of nonuniform photo intensity, then the estimates of forest and nonforest acreage will be biased. All other inventory statistics, even those that come only from the field plots, will also run the risk of being biased. Any relationship between photo intensity and ground elevation would also be likely to bias most of the inventory estimates, because such forest characteristics as species type, site index, stand volume,

and growth tend to be associated with elevation. A second reason for the interest in elevation is that it might explain any differences in photo intensity between forest and nonforest lands. That is, a difference in average photo intensity between forest and nonforest lands might be due primarily to the fact that the forest lands were at a different average elevation than the non-forest lands.

The specific objectives of the study, then, were to answer these four questions:

1. Is there a significant difference in photo intensity between forest and nonforest lands?
2. Is this difference consistent among photo projects?
3. Is there a significant relationship between photo intensity and ground elevation?
4. If the answers to questions 1 and 3 are both "yes," then, is elevation responsible for all or part of the difference in photo intensity between forest and nonforest lands? In other words, is there a significant difference between forest and nonforest photo intensity after both have been adjusted to a common elevation?

PROCEDURES

The six photo projects chosen for testing were the widely available U.S. Department of Agriculture, ASCS (Agricultural Stabilization and Conservation Service), projects at 1:20,000 scale. The particular counties selected, primarily because photo indexes were available, were Benton, Douglas, Jackson, and Lane in Oregon and Clark and Lewis in Washington. These projects were flown by three different aerial contractors, most in 1960. Ground elevations ranged from 200 to 3,000 feet.

The measure of photo intensity used was the number of photos per standard township. Because actual townships vary somewhat in size and shape, a series of idealized townships exactly 6 miles on a side were laid out on topographic quadrangles. These boundaries were then carefully transferred to photo index mosaics, by matching natural and cultural detail, and the number of photos in each township was counted. Since photo plot grids established on aerial photos are commonly restricted to the theoretical effective area, the net area assuming 60-percent endlap and 30-percent sidelap, the photo count was based on the number of effective areas, including estimated fractional ones, that fell within the township boundary. Thus, the count of photos per township was proportional to the number of photo plots that would be expected to fall in that township.

Each standard township was classified as being principally forest or non-forest, a subjective judgment based on its appearance in the photo index mosaic. The average elevation of each township was estimated by determining from topographic quadrangles the elevation at each of 36 grid points and averaging these.

Thus, the basic data for the study consisted of observations of a series of standard townships within each of six photo projects. For each township, the observations were: (1) number of photo effective areas and fractions thereof, (2) principal land class, either forest or nonforest, and (3) average elevation. The number of townships used in each county photo project ranged from 17 to 35.

ANALYSIS AND RESULTS

Table 1 shows the basic data of average photo intensity for forest and nonforest lands in each of the six county photo projects. The photo intensity for nonforest land exceeded that for forest land in every county, ranging from 0.8 percent to 5.7 percent greater. The weighted mean difference in photo intensity between forest and nonforest lands was 0.70 photo per township. Thus, overall, photo intensity on nonforest lands was 4.1 percent greater than that on forest lands.

Table 1.--*Average photo intensity by land class and photo project*

Photo project (county)	Number in sample			Photo intensity per township			Difference as percent of forest
	Forest	Nonforest	Total	Forest	Nonforest	Difference	
Benton	12	5	17	17.10	18.08	+0.98	+5.7
Clark	5	12	17	17.68	17.82	+.14	+.8
Douglas	16	6	22	16.53	16.75	+.22	+1.3
Jackson	11	9	20	16.47	17.22	+.75	+4.6
Lane	19	16	35	16.56	17.42	+.86	+5.2
Lewis	20	11	31	18.42	19.41	+.99	+5.4
Total or weighted mean	83	59	142	17.13	17.83	+.70	+4.1

The statistical significance of this overall difference and its consistency among photo projects were tested by an analysis of variance with disproportionate subclass frequencies. The results are shown in table 2, and they confirm what seems apparent from inspection of the basic data.

The difference in average photo intensity between forest and nonforest land classes is highly significant; that is, it is not likely to have been caused by a sampling accident. This answers the first question posed in the study objectives. The interaction between land class and photo project is not significant. This is interpreted to mean that the differences between forest and nonforest photo intensities are reasonably consistent between photo projects. This answers the second question.

Table 2.--*Analysis of variance for photo intensity*

Source of variation	DF	SS	MS	F
Land class (forest-nonforest)	1	16.69	16.69	26.00**
Photo project (county)	5	88.81		
Interaction (error)	5	3.21	.64	1.14
Within cells	130	73.17	.56	
Total	141	181.88		

**Significant at the 1-percent level.

To test the relationship between photo intensity and ground elevation, a covariance analysis was made with elevation as the covariate. The results showed the correlation between elevation and photo intensity to be nonsignificant. To confirm the logic of this result, the individual regressions of photo intensity on ground elevation were examined for each of the 12 groups of data--six photo projects with forest and nonforest classes in each. These regressions were about equally divided between positive and negative slopes, and most were not significantly different from zero.

Thus, it is evident that there is no significant relationship between photo intensity and ground elevation, which answers the third question posed under "objectives." This also answers the fourth question, for if elevation does not influence photo intensity, then it cannot be responsible for the difference in photo intensity between forest and nonforest lands. Some factor other than elevation must be responsible.

INTERPRETATION OF RESULTS

This study has shown that within a photo project, aerial photos are not necessarily uniformly distributed over the earth's surface. It has also shown that irregularities in this distribution are not necessarily random but can be associated with items of interest, such as the land class breakdown of forest and nonforest. The lack of association with elevation suggests that nonuniform photo distribution can occur even when the ground is level. This also means that most of the recommended procedures for removing scale-change bias--using photo centers only, radial line location of plot clusters on stereopairs, and plot weights based on elevation--will not eliminate the risk of bias caused by nonuniform photo intensity. Therefore any forest inventory using plots selected on aerial photos with equal probability runs the risk of obtaining biased estimates.

This limited study can only hint at the frequency and magnitude of the bias that might be expected. No doubt there are photo projects where it is negligible, but there may be some where it is catastrophic. Photo intensity over nonforest land averaged 4.1 percent greater than that over forest land in the six projects tested. The error in estimating acreages of forest and nonforest lands will be less than this figure, the magnitude depending on the relative proportions of the two land classes. For example, with a nonforest photo intensity 4.1 percent greater than forest and an inventory area that is 60-percent forest land, the forest area will be underestimated by 1.6 percent, and the nonforest area will be overestimated by 2.4 percent.

Whether or not biases of this magnitude constitute a serious problem depends on the inventory objectives. If one is simply making a rough reconnaissance and would be satisfied with area estimates having sampling errors of 15 or 20 percent, biases in the amount of a few percent would not be serious. On the other hand, there seems little point in attempting to achieve sampling errors as low as, say, 5 percent if there is likely to be a bias of several percent. One authority states that the effect of bias on the accuracy of an estimate is negligible if the bias is less than one-tenth the standard error of this estimate (*5*).

It is not possible to determine with certainty the reasons for the difference in photo intensity between forest and nonforest lands. However, a clue to the probable reason lies in the ASCS aerial photography specifications. These require centering of photos on section corners with successive camera stations 1 mile apart. At a photo scale of 1:20,000, this produces an endlap of 65 percent. Where section lines are readily visible, principally in urban and agricultural areas, this specification is enforced. However, where section lines are not visible, as in forested areas, the specification is not enforced, and minimum acceptable endlap is 60 percent, or in some cases, 55 percent. This, of course, will tend to produce fewer photos per unit of forest land than nonforest land.

If this is indeed the explanation for the difference in photo intensity, then we might be tempted to assume that bias from this source is limited to ASCS photography and to areas where forest and nonforest lands occur in substantial blocks rather than intermingled in small pieces. This is probably a risky assumption. There are undoubtedly many other causes of nonuniform photo intensity, and it is possible that some of these could produce a bias greater than those shown in this study.

There is no assurance that any photo project has been free from bias due to difference in photo intensity. There may be certain kinds of photo projects or certain parts of the country where serious bias from this source is rare. However, the *risk* is always present, and unless steps are taken to remove it, there is always the possibility that our inventory estimates are not as reliable as their sampling errors would suggest.

The one sure way of eliminating photo plot bias from all sources is to select plot locations in some unbiased manner on maps, then to transfer these

locations to photos using radial line or stereoplotter instruments. This procedure is currently being used on several forest inventories in Canada.

Although little information is available on the cost of this map-transfer process, it is considered too expensive by many inventory foresters, and cheaper alternatives have been sought. There appears to be no cheap alternative that eliminates bias due to scale change as well as that due to irregular photo distribution. However, for parts of the country where scale change bias is considered inconsequential, it is possible to develop shortcut methods for minimizing the bias from nonuniform photo distribution.

Examples of such procedures are those used by the nationwide Forest Survey conducted by the U.S. Forest Service. In the North Central Region, uncontrolled mosaics are constructed for each township. Township boundaries are then transferred from maps to the mosaics, and equal numbers of photo plots are systematically located within each township. In the Southern Region, Forest Survey field plots are established by a systematic grid on maps. These locations are transferred to aerial photos, and a cluster of photo plots is then established on each photo containing a field plot.

As yet, little seems to be known about the cost of the various methods or their degree of success in eliminating or minimizing the bias in photo plot sampling. More needs to be done to develop this information and make it available. Until this happens, inventory foresters who want to take advantage of aerial photo plots will have to rely mainly on intuition in deciding what to do about the risk of bias associated with these plots. They can locate plots systematically on the photos and accept the risk of bias from both scale change and irregular photo distribution. They can pay whatever it costs to eliminate bias by the map-transfer process. Or they can adopt some substitute procedure which will presumably be cheaper than map transfer, yet minimize the risk of bias from irregular photo distribution.

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